



Integrating indigenous knowledge and GIS for flood-resilient crop planning in the Brahmaputra Basin

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Abstract

This research addresses agricultural vulnerability in the Brahmaputra Basin by proposing a hybridized framework that integrates Indigenous Knowledge (IK) with Geographic Information Systems (GIS). Historically, top-down, techno-centric interventions have failed to account for micro-topographical complexities and local hydrological behaviors. To bridge this gap, this study employs Participatory GIS (PGIS) to formalize tacit community expertise—such as flood-adaptive cropping and soil management—into quantifiable spatial data layers. By synthesizing longitudinal ethnographic insights with digital elevation models, the framework enhances the accuracy of inundation mapping and agricultural zoning. A critical finding is the necessity of "co-production," wherein high-resolution technical projections are validated through continuous community-led ground-truthing. This iterative feedback loop transforms static hydrological modeling into a dynamic, adaptive system responsive to intensifying monsoon volatility. Ultimately, the research provides a scalable, transdisciplinary model for climate adaptation, demonstrating that systemic food security is best achieved when technological tools serve as vessels for ancestral ecological wisdom. By centering marginalized smallholder farmers as active stewards of geospatial data, this study offers a robust blueprint for equitable disaster risk reduction and resilient land-use planning in climate-vulnerable riverine ecosystems globally.

Keywords: Brahmaputra Basin, Participatory GIS, Indigenous Knowledge, Climate Adaptation, Agricultural Resilience

1. Introduction

The Brahmaputra Basin, a transboundary river system crossing Tibet, India and Bangladesh, represents one of the most ecologically dynamic landscapes in South Asia. Characterized by extreme monsoon-dominated precipitation and complex fluvial geomorphology, the basin is inherently prone to seasonal inundation. Historically, the inhabitants of the Brahmaputra valley have treated flooding as a periodic pulse essential for soil nutrient replenishment (Boruah et al., 2021). However, in recent decades, the convergence of anthropogenic-climate change, deforestation and unplanned urbanization has

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disrupted these natural rhythms, transforming traditional seasonal high waters into catastrophic, unpredictable and prolonged flood events. This intensification poses an existential threat to the region's agrarian economy, necessitating a paradigm shift from reactive disaster management to proactive, adaptive crop planning.

The current challenge lies in the limitation of top-down agricultural planning, which often ignores the granular, site-specific realities of the basin. While modern scientific methodologies offer sophisticated spatial analysis tools, they frequently lack the nuanced, historical data required to navigate the socio-ecological complexity of floodplains. Conversely, Indigenous Knowledge (IK)—the cumulative form of practice, belief and experience preserved by local communities—provides longitudinal insights into flood behavior, crop resilience and soil fertility that exceed standard climatic modeling (Berkes, 2017). The integration of IK with Geographic Information Systems (GIS) presents a combined pathway to synthesize these disparate knowledge domains, creating a strong framework for flood-resilient agriculture.

GIS serves as the technological backbone of this integration, allowing for the spatial modeling of flood vulnerability, hydrological flow patterns and land-use dynamics. By incorporating IK, however, the GIS framework moves beyond mere physical topography. Incorporating local expertise allows researchers to map "micro-niches"—areas where specific indigenous rice varieties or flood-tolerant legumes have historically thrived despite inundation. As argued by Prasad et al. (2020), the spatial representation of community-identified flood markers, such as historical high-water marks and traditional siltation patterns, provides a layer of ground-truth data that remote sensing alone cannot capture. This participatory GIS (PGIS) approach ensures that technological interventions are not abstract scientific outputs but are rooted in the lived experience of the farmers who will implement them.

The methodology for this integration requires a multi-scalar approach. Initially, qualitative data must be gathered through participatory mapping sessions where farmers identify high-risk agricultural zones and resilient crop varieties based on ancestral knowledge. This data is then translated into vector and raster formats for integration into a GIS environment. By overlaying this qualitative data with objective hydrological satellite imagery and topographical data, stakeholders can generate high-resolution suitability maps. These maps facilitate precise decision-making, such as identifying zones for floating gardens, floating seedbeds, or the adoption of short-cycle, stress-tolerant crop varieties during the pre-monsoon transition (Chakraborty & Mukherjee, 2022).

Beyond the technical utility, this integration fosters social inclusivity in climate adaptation. Participatory methodology ensures that the "experts"—the smallholder farmers—remain central to the planning process, thereby increasing the likelihood of community adoption and long-term sustainability. When agricultural strategies are co-produced, they resonate with the cultural, economic and practical constraints of the local population. This is particularly vital in the Brahmaputra Basin, where the demographic is largely composed of marginalized communities whose livelihoods are inextricably linked to the river's fluctuations.

The fusion of Indigenous Knowledge and GIS is not merely a technical exercise but a transformative approach to climate resilience. By bridging the gap between historical wisdom and geospatial precision, this model offers a path toward sustainable agrarian development that respects the ecological agency of the river basin. As the Brahmaputra region continues to face the volatile impacts of environmental change,

adopting such transdisciplinary frameworks will be essential to ensuring food security, fostering community resilience and maintaining the ecological integrity of this unique landscape.

2. The Role of Indigenous Knowledge and GIS in Flood-Resilient Agriculture

The Brahmaputra Basin, a complex hydrological landscape characterized by extreme seasonal variations, serves as the lifeline for millions. Yet, this ecological vitality is shadowed by persistent vulnerability to catastrophic flooding. Historically, the diverse agro-ecological systems within this basin have thrived through the application of Indigenous Knowledge (IK)—a sophisticated, time-tested repository of ecological wisdom. As anthropogenic climate change intensifies the unpredictability of monsoon patterns, the efficacy of traditional adaptation strategies faces unprecedented strain. In this context, the synergy between IK and Geographic Information Systems (GIS) emerges not merely as an academic exercise, but as a critical imperative for ensuring food security and agricultural sustainability in one of the world's most flood-prone regions.

Indigenous Knowledge in the Brahmaputra Basin is a dynamic system of observation and practice. Over generations, communities have developed an intricate understanding of micro-topography, soil pedology and hydrological rhythm. Traditional practices, such as the cultivation of deep-water rice varieties (*Bao* rice) and the strategic spatial arrangement of crops on high-ground (*bhiti*) versus low-lying (*bheel*) lands, reflect a deep-rooted capacity to synchronize agricultural cycles with the pulse of the river (Das et al., 2021). These practices are not static; they represent a continuous evolution of environmental observation. However, the current climate crisis, marked by "flashier" floods and prolonged waterlogging, has accelerated beyond the historical experience that shaped these traditional techniques, necessitating the integration of contemporary analytical tools.

Geographic Information Systems (GIS) offer a robust platform for modernizing these ancestral defenses. GIS facilitates the synthesis of multi-dimensional data, including digital elevation models (DEMs), land-use/land-cover (LULC) classifications and hydrological modeling. By mapping flood-prone areas with high precision, GIS enables the identification of vulnerable nodes that were previously only understood through qualitative experience. When historical flood records are overlaid with soil suitability data, researchers and farmers can move from reactive mitigation to proactive spatial planning.

The integration of IK into GIS frameworks allows for the "spatialization" of local wisdom. For example, when indigenous farmers identify specific areas that remain buoyant during high-water events, GIS can validate this observation through topographic wetness indices and soil drainage analysis. This creates a hybridized knowledge base; while IK provides the "who, what and where" of resilient crops, GIS provides the "how much and how often" through predictive modeling (Borah & Nath, 2020).

The true power of this integration lies in enhancing the decision-making capacity of the farming community. Climate change has rendered traditional temporal markers—such as the timing of the first rains—increasingly unreliable. By utilizing GIS-based spatial modeling, farmers can gain access to refined predictive scenarios that simulate flood inundation under varied rainfall intensities. This enables more precise crop planning, such as the strategic selection of short-duration, flood-tolerant varieties or the adjustment of sowing dates to avoid peak discharge periods. Moreover, GIS can facilitate the landscape-

level design of flood mitigation infrastructure. Traditional techniques, such as the construction of *khels* (drains) or the maintenance of riparian buffer zones, can be optimized through GIS-based watershed management models. By planning these interventions on a basin-wide scale rather than solely on a plot-by-plot basis, communities can create more comprehensive, resilient agricultural landscapes that mitigate the impact of downstream flooding while preserving the nutrient-rich sediment deposition vital to basin fertility (Islam et al., 2022).

The integration of scientific tools with traditional practices adheres to the principle of "co-production of knowledge." This approach acknowledges that top-down, purely technical solutions often fail because they ignore the sociocultural contexts of the Brahmaputra peasantry. Conversely, purely traditional methods may struggle to keep pace with the velocity of environmental shift. By grounding GIS interventions in the context of Indigenous Knowledge, the resulting strategies are more likely to be culturally accepted and locally sustainable.

Moreover, this integration serves as a tool for the preservation of cultural memory. As younger generations move away from traditional agrarian lifestyles, the translation of qualitative Indigenous knowledge into digital, GIS-stored datasets ensures that this wisdom is not lost to time. It transforms fluid, oral traditions into tangible, actionable data that can be used to inform policy and agricultural extension services.

The Brahmaputra Basin serves as a microcosm for the global challenges of climate adaptation. The discourse on knowledge integration—merging the technological precision of the Global North with the localized adaptation of the Global South—is essential for disaster risk reduction (DRR). By validating Indigenous practices through spatial analysis, researchers provide a replicable model for other deltaic and riverine regions, from the Mekong to the Nile.

Ultimately, the goal of this integrative approach is to transition from a cycle of annual disaster-relief dependence to one of systemic, climate-ready agricultural production. While technology provides the necessary foresight, Indigenous Knowledge provides the essential context. Together, they form a formidable barrier against the uncertainties of a changing climate, ensuring that the people of the Brahmaputra Basin can continue to farm in harmony with the volatile tides of their river for generations to come.

3. Geography and Characteristics of the Brahmaputra Basin

The Brahmaputra River Basin represents one of the most complex, ecologically vibrant and hydrologically volatile river systems in South Asia. Spanning over 580,000 square kilometers, this transboundary basin serves as a critical life-support system for millions across China (Tibet), India, Bhutan and Bangladesh. Originating from the glaciers of the Kailash Range in the Tibetan Plateau, the river descends through a dramatic altitudinal gradient, transitioning from high-altitude permafrost and alpine ecosystems to the expansive, sediment-rich alluvial plains of Assam and the intricate deltaic wetlands of Bangladesh before discharging into the Bay of Bengal. This vast basin is not merely a geographic feature but a socio-ecological crucible, defined by a unique interplay of topography, extreme monsoon-driven hydrology and deep-rooted human adaptations (Goswami, 2017).

The basin's character is fundamentally defined by its hydro-climatic regime, dictated by the South Asian monsoon. The dual influence of high-intensity monsoon rainfall and glacial melt creates a distinct hydrological seasonality. The wet season, occurring from June to September, often results in catastrophic discharge levels, while the period from October to May experiences significantly reduced flow. This extreme variability, often referred to as a "pulse" system, is the primary architect of the basin's geography. The river's high sediment load—among the highest in the world—is deposited across the floodplains, a process that naturally renews soil fertility but simultaneously makes the landscape inherently unstable and prone to frequent river channel shifts (Chakravarty et al., 2020).

These floods are a double-edged sword. While they replenish the vital nutrients required for the region's intensive agricultural output, they also represent a constant existential threat to human settlements. As climate change intensifies the variability of the monsoon, the historical cyclicity of these floods has become less predictable, leading to an increase in the frequency of "flash" events that deviate from traditional agricultural calendars, thus challenging the resilience of the rural population.

Agriculture forms the backbone of the basin's socio-economic structure. The fertile alluvial plains support intensive cultivation of rice, which is the primary caloric source for millions. Indigenous communities in the Brahmaputra valley have, for centuries, manifested a sophisticated "culture of living with floods." Traditional practices involve the selection of flood-tolerant rice varieties—often referred to as *deep-water rice* or *floating rice*—and the utilization of integrated farming systems that treat floodwaters as a resource rather than a hazard.

However, the late 20th and early 21st centuries have seen a paradigm shift toward structural interventions, such as the construction of massive embankments, dams and barrages. These top-down engineering solutions, aimed at "taming" the river, have frequently yielded counter-intuitive results. By obstructing natural drainage and interrupting the sediment pulse, these structures have often exacerbated siltation, leading to bed aggradation and higher water levels in nearby areas, thereby increasing the vulnerability of downstream communities (Bhattacharyya, 2018). The loss of traditional ecological knowledge (TEK) in the face of centralized planning has created a significant gap in disaster risk reduction, highlighting the limitations of purely techno-centric approaches to river management.

As climate variability threatens to surpass the thresholds of traditional adaptive capacity, there is an urgent need for a more robust, integrative approach to flood management. The fusion of Geographic Information Systems (GIS) with Indigenous Knowledge (IK) is emerging as a critical framework for building climate resilience. GIS allows for the spatial modeling of flood extents, land-use patterns and soil topography with high granular precision. When this analytical power is combined with the localized, time-tested wisdom of indigenous farmers—who possess granular knowledge of micro-topography, historic flood timings and local crop resilience—the result is a highly effective, community-centric agricultural strategy (Sarma et al., 2021).

For instance, whereas spatial data can identify where the highest risk of inundation lies, indigenous knowledge explains *why* certain plots remain productive during such events. By mapping these specific ecological niches using GIS, stakeholders can transition from reactive disaster management to proactive, site-specific agricultural planning. This integration enables the identification of optimal sowing times and

the selection of appropriate crops that minimize losses while maximizing the beneficial aspects of the sediment-rich floods.

The Brahmaputra Basin remains a landscape of immense potential and profound risk. The current epoch of climate uncertainty demands that researchers and policymakers look beyond structural barriers and prioritize adaptive, nature-based and human-centric solutions. The reliance on centralized, large-scale infrastructure has often alienated local stakeholders and ignored the complex ecological reality of the river. Moving forward, the successful governance of this basin will depend on our ability to respect the river's natural dynamism while leveraging digital intelligence to support the resilience of those who call the basin home. By fostering a dialogue between the quantitative rigor of geospatial analysis and the qualitative richness of indigenous wisdom, the region can move toward a more sustainable and equitable future. The following section will detail the specific methodological framework designed to operationalize this integration, setting the stage for a new paradigm in flood-resilient agricultural planning.

4. Materials and Methods: Integrating Indigenous Knowledge and GIS

The Brahmaputra Basin, characterized by its volatile hydrological regime and perennial flooding, necessitates highly adaptive agricultural strategies. For generations, the Indigenous communities of this region have cultivated a sophisticated body of Indigenous Knowledge (IK), comprising centuries of empirical observations regarding riverine dynamics and crop resilience. However, conventional agricultural planning has frequently marginalized this knowledge in favor of top-down, purely technocratic models. To rectify this, this study employs a mixed-methods approach to integrate IK with Geographic Information Systems (GIS), creating a robust, culturally grounded framework for flood-resilient crop planning.

The study utilizes a convergence of qualitative ethnographic data and quantitative spatial analysis to bridge the gap between traditional wisdom and modern geospatial technology. By employing participatory mapping and GIS-based multi-criteria decision-making, the project ensures that the resulting agricultural framework is not only scientifically rigorous but also ecologically and socially relevant (Chambers, 2006).

Field Research and Qualitative Data Gathering Fieldwork was conducted across diverse riparian communities in the Brahmaputra Basin. Given the region's unique socio-ecological history, local agricultural practices serve as an invaluable archive of disaster adaptation. Ethnographic interviews were conducted with key informants—specifically elders, traditional farmers and local agricultural practitioners—to document indigenous methodologies. The data collection focused on two primary pillars: identification of flood-tolerant crop cultivars (such as deep-water rice varieties) and the traditional water-management systems that have historically buffered the community against seasonal inundation. This qualitative phase provided the "thick description" necessary to interpret geospatial data within its specific cultural context.

Geospatial Analysis and Modeling In parallel, a quantitative GIS dataset was constructed to map the physical environment. Utilizing Digital Elevation Models (DEM), historical satellite imagery and hydrological records from the Brahmaputra Board, we mapped flood frequency, amplitude and soil drainage characteristics. The integration of high-resolution topographic data allowed for the identification of micro-topographic variations that, while invisible to macro-level governmental planning, are critical for local

agricultural success. By overlaying soil suitability indices with longitudinal flood-inundation data, the model established a baseline for "geospatial risk," which serves as the foundation for modern predictive modeling.

The heart of this methodology lies in the participatory GIS (PGIS) sessions. Unlike extractive research, this study invited local experts to co-produce the spatial model. During collaborative mapping workshops, farmers overlaid their qualitative insights regarding "flood-resilient zones" onto GIS-generated maps.

This process facilitated a critical feedback loop. For instance, where GIS data might suggest a particular area as "high risk" due to inundation, indigenous participants clarified that specific traditional soil-management techniques or flood-tolerant landraces could thrive, effectively reclassifying the area's utility. This collaborative mapping process allowed for the systematic weighting of variables. A multi-criteria decision analysis (MCDA) was employed, wherein the criteria for "crop suitability" were modified by the weighting provided by the community informants. This ensured that the GIS model did not merely represent topography, but represented a synthesized, lived geography (McCall & Minang, 2005).

The validity of the integrative framework was established through an iterative process of field observations and community-led ground-truthing. Predicted suitability zones were compared with actual crop outcomes in subsequent flood events. Discrepancies between the model's performance and the actual yields were treated as vital data points, prompting refinements to the algorithmic weighting of the GIS model. This feedback loop ensured the longitudinal sustainability of the model, allowing it to adapt to the shifting hydrological patterns driven by climate change in the Brahmaputra Basin. Such participatory validation not only enhances the accuracy of the model but serves to empower local communities, treating them as co-researchers rather than passive subjects.

The integration of IK and GIS transcends the mere technical mapping of land. It acknowledges that agricultural survival in the Brahmaputra Basin is predicated on the synergy between the "human" and the "geophysical." By institutionalizing indigenous perspectives within the GIS framework, this research provides a model that is both adaptive and culturally respectful.

The resulting framework demonstrates that top-down, standardized agricultural policies are insufficient for the extreme variability of the Brahmaputra landscape. Instead, the future of food security in this region lies in "hybridized knowledge systems"—where the digital precision of GIS acts as a vessel for the traditional, time-tested wisdom of Indigenous farmers. Ultimately, this methodology offers a template for similar regions worldwide, proving that technological advancements are most effective when they are firmly rooted in the local knowledge systems that have enabled survival for centuries.

5. Results and Discussion

The Brahmaputra Basin, characterized by its complex hydrological regime and recurring monsoon-driven inundations, represents a critical frontier for climate-adaptive agriculture. As global climate change intensifies the unpredictability of flood cycles, traditional top-down agricultural models have often proven insufficient. The recent paradigm shift towards the integration of Indigenous Knowledge (IK) with Geographic Information Systems (GIS) has, however, offered a robust methodological framework for

developing flood-resilient crop planning strategies. By synthesizing the localized, empirical wisdom of riverine communities with the precision of geospatial analysis, this approach not only enhances the accuracy of flood risk assessments but also fosters sustainable agricultural adaptation.

Synergizing Traditional Wisdom with Geospatial Precision

The collaborative framework established in recent studies demonstrates that GIS serves as a powerful conduit for formalizing the tacit knowledge held by indigenous farmers. While GIS provides high-resolution data on elevation models, drainage networks and historical flood inundation extents, it often lacks the nuanced ground-truth that local farmers possess regarding soil behavior and micro-climatic shifts.

A pivotal finding in this integration is the identification of flood-tolerant agrobiodiversity. Indigenous farmers in the Brahmaputra Basin have cultivated specific heirloom rice varieties—such as *Bao* or deep-water paddy—that possess unique phenotypic expressions adapted to waterlogged conditions. Unlike high-yielding, modern varieties that succumb to rapid submergence, these traditional cultivars exhibit stem elongation and physiological plasticity, allowing them to thrive during prolonged inundation. When these traditional varieties are mapped using GIS-based soil-moisture and duration modeling, the synergy creates a predictive capability that confirms why these crops persist where others fail. Furthermore, the root structures of these indigenous varieties provide essential ecosystem services, acting as natural anchoring mechanisms that stabilize riparian soil against the scouring effects of high-velocity peak flows (Sarkar et al., 2021).

Spatial Variability and Targeted Agricultural Planning

The Brahmaputra Basin is not a monochromatic flood zone; rather, it is a mosaic of varying hydrological risk. GIS-based analysis reveals that topographical features—such as natural levees (*bheels*), crevasse splays and back swamps—dictate the intensity and duration of flooding. By integrating Indigenous mental maps with Digital Elevation Models (DEM), researchers have successfully delineated high-risk zones from more stable, elevated plots.

This spatial granularity allows for highly targeted crop planning. For instance, low-lying, high-risk inundation zones are identified as sites for flood-resilient paddy, while slightly elevated terraces are mapped for diverse intercropping and agroforestry systems. This targeted planting strategy, informed by both GIS-suitability indices and traditional ecological knowledge (TEK), optimizes land use efficiency. According to Berkes (2018), the inclusion of local stakeholders in spatial decision-making transforms the agricultural landscape from a vulnerable entity into a resilient one, as it encourages farmers to utilize water management techniques that harmonize with the natural landscape rather than fighting against it.

Participatory Mapping and Temporal Alignment

Perhaps the most significant contribution of this integrated approach is the alignment of modern agricultural calendars with traditional hydrological cycles. Participatory mapping sessions conducted with farmers have revealed a sophisticated understanding of phenology tied to the Brahmaputra's pulse. Farmers demonstrate an intricate knowledge of "flood-cues," such as the timing of the pre-monsoon showers and the behavior of local aquatic flora, which signal the onset of specific flood phases.

When these qualitative temporal cues are cross-referenced with GIS-facilitated longitudinal data of historical flood events, they produce a comprehensive "agricultural calendar" that is both scientifically grounded and locally relevant. This alignment empowers farmers to refine their planting and harvesting schedules to avoid the peak flood windows, thereby minimizing the risk of crop failure. As noted by Mapfumo et al. (2013), participatory GIS (PGIS) functions as a bridge between scientific data and community agency, ensuring that technological interventions remain culturally acceptable and economically viable for local populations.

Validating Resilience and Empowering Communities

The validation of the GIS-IK integrated model through multi-season field observations underscores its efficacy. In areas where farmers adopted planting schedules and crop varieties explicitly mapped via this model, there was a measurable reduction in crop loss during significant flood events. The yield stabilization observed in these regions is a testament to the fact that spatial planning, when informed by ancestral expertise, is more resilient than localized attempts that rely solely on external data.

Beyond the quantification of yield and risk reduction, this integration has a profound social dimension. By validating the traditional practices of indigenous farmers through formal scientific mapping, the process restores legitimacy to local knowledge systems that have historically been marginalized. This empowerment is crucial for long-term sustainability. As these communities become actively involved in the geospatial mapping of their lands, they transition from passive recipients of climate-adaptation strategies to active stewards of their agricultural future (Tengö et al., 2017).

The integration of Indigenous Knowledge with GIS in the Brahmaputra Basin demonstrates that the path to climate resilience lies in the convergence of diverse knowledge systems. By bridging the gap between local lived experience and precision geospatial technology, it is possible to create adaptive agricultural frameworks that are robust enough to withstand the volatile hydrological patterns of the future. This holistic approach not only preserves essential agrobiodiversity but also transforms the way we perceive and manage flood-prone landscapes, turning inherent risks into opportunities for sustainable development.

The integration of Indigenous Knowledge (IK) with Geographic Information Systems (GIS) presents a transformative frontier in disaster risk reduction and sustainable agriculture. While this synthesis offers a robust framework for flood-resilient crop planning in the Brahmaputra Basin, the study highlighted significant structural and socio-cultural challenges. Bridging the gap between empirical geospatial data and tacit, community-held wisdom requires navigating complex landscape variables, socio-economic disparities and the dynamic nature of climate-induced environmental shifts.

Addressing Socio-Cultural Variability and Disparity

A primary obstacle identified in the research is the inherent heterogeneity in how different communities perceive flood risks and formulate agricultural resilience strategies. Indigenous systems of knowledge are rarely monolithic; they are deeply contextual and rooted in the historical interactions between specific ethnic groups and their local ecosystems. As noted by Berkes (2012), Indigenous knowledge is not merely a collection of data points but a complex system of practice and belief. The study observed that while certain communities in the Brahmaputra Basin possess sophisticated, multi-generational understandings of flood

morphology and crop-specific resilience, other communities—often those marginalized by socio-economic factors—lack the resources or the recent historical continuity necessary to adapt traditional practices to rapid environmental change.

This disparity necessitates a move away from "one-size-fits-all" GIS integration. Instead, a tailored, site-specific methodology is required. To ensure an inclusive GIS framework, researchers must move beyond mere data extraction and engage in sustained, participatory dialogue. By respecting the diverse epistemological foundations of these communities, the resulting GIS maps become more than just digital overlays; they become collaborative tools that reflect the specific vulnerabilities and strengths of local populations (McCall & Minang, 2005).

The Imperative of Dynamic Feedback Loops

The study underscored that the relationship between GIS modeling and agricultural practice cannot be static. While the initial integration successfully identified optimal planting zones and flood-resilient varieties, the efficacy of these models is contingent upon continuous feedback loops. Climate change is currently altering historical flood patterns in the Brahmaputra Basin, rendering static hydrological projections increasingly obsolete.

Consequently, there is a critical need for adaptive management. Models must be iteratively updated through a synergistic process: as floods manifest in real-time, local observations about crop success or failure must be fed back into the GIS framework. This process relies on a "co-production of knowledge," where technical GIS capabilities are bridged with the longitudinal observations of local farmers (Breidlid, 2013). Without this, the GIS intervention risks becoming disconnected from the reality of an evolving landscape. Sustaining these feedback loops requires not just technical prowess, but a long-term commitment to community engagement that outlasts the traditional grant-cycle duration of research projects.

Standardizing Documentation and Empowering Communities

To address these challenges, the study advocates for a dual strategy: formalizing methodology and capacity building. The creation of a standardized, ethical repository for documenting Indigenous agricultural practices could significantly enhance the coherence of spatial data. This repository would serve as a living archive, allowing researchers to map resilience strategies systematically while ensuring that the intellectual property and cultural context of the Indigenous knowledge remain protected. Such a resource acts as a cornerstone for future disaster risk management policies in flood-prone regions worldwide.

Moreover, the study champions the establishment of community-based GIS training programs. Transitioning GIS from an expert-driven tool to a community-owned asset is essential for scalability. When local farmers are trained to interpret and update spatial data, they transition from being subjects of a study to active participants in environmental management. This fosters a sense of ownership, which is a verified driver of sustainable development (Chambers, 1997). By equipping local stakeholders with these tools, the community can perform real-time monitoring, thereby enhancing the overall resilience of the agricultural landscape.

Toward an Inclusive Collaborative Paradigm

The integration of IK and GIS should be viewed as a dynamic, ongoing negotiation between diverse stakeholders, including academic researchers, local farmers and governmental policymakers. The Brahmaputra Basin serves as a microcosm of the global climate crisis and the success of resilience strategies here hinges on an inclusive dialogue that respects diverse knowledge systems. Scientific objectivity is not inherently superior to Indigenous wisdom; rather, when combined, they offer a holistic view of the landscape that is both technologically precise and culturally profound.

The study's findings demonstrate that the synergy between Indigenous Knowledge and GIS technology provides a powerful, multi-dimensional approach to crop planning. By moving beyond the initial mapping phase to embrace a model of continuous, inclusive and decentralized knowledge exchange, the project establishes a robust template for the future. The long-term viability of agriculture in the Brahmaputra Basin depends on this collaborative paradigm, ensuring that interventions are not only scientifically sound but also socially resilient and locally meaningful.

6. Conclusion

The integration of Indigenous Knowledge (IK) with Geographic Information Systems (GIS) for flood-resilient crop planning in the Brahmaputra Basin represents a paradigm shift in how we approach sustainable agriculture amidst the accelerating crises of climate change. For centuries, the agrarian communities residing within the floodplains of the Brahmaputra have developed sophisticated empirical strategies to navigate the erratic hydrological cycles of one of the world's most dynamic river systems. By synthesizing this deep-seated, generational wisdom with the precision of spatial analysis through GIS, researchers have established a transformative model for agricultural resilience. This study underscores the vital necessity of reconciling local ontologies of the land with modern technological frameworks, ultimately proving that sustainable development is best achieved when scientific rigor is informed by the lived realities of those who interact with the land daily.

The Brahmaputra Basin is characterized by its high susceptibility to extreme flooding, sediment deposition and erratic lateral channel migration. Traditional agricultural practices—such as floating bed cultivation, the selection of flood-tolerant rice varieties and the strategic timing of planting according to moisture-retention patterns—have historically acted as crucial defense mechanisms. However, climate change has rendered these traditional indicators increasingly unreliable. The integration of GIS offers a solution by mapping these flood regimes with unprecedented spatial accuracy. When Indigenous Knowledge regarding land topography, soil fertility and ancestral flood recurrence intervals is layered into GIS databases, the resulting models gain a granularity that purely satellite-derived data often lacks. This synergy validates local observations while enhancing their efficacy; for instance, GIS can translate a farmer's qualitative knowledge of "high-risk zones" into actionable, quantitative land-use maps, allowing for more precise, adaptive agricultural zoning that accounts for the specificities of the Brahmaputra's hydrology.

As climate change intensifies, the lessons derived from this integrative approach are imperative for the formulation of forward-looking land-use policies. Historically, mainstream agricultural and disaster management policies have often marginalized local knowledge, favoring top-down, standardized interventions that frequently ignore the ecological heterogeneity of flood-prone regions. The findings of

this research strongly advocate for a policy transformation that institutionalizes the inclusion of Indigenous Knowledge. By creating frameworks that harmonize traditional insights with scientific GIS modeling, policymakers can construct comprehensive strategies that are empathetic to the unique geographical challenges faced by local populations. This inclusive approach not only bolsters the systemic effectiveness of resilience strategies but also serves as a crucial social function: it empowers local communities by centering their expertise within the decision-making apparatus, thereby fostering a sense of agency and dignity in the face of climate instability.

Furthermore, this study emphasizes the absolute criticality of participatory methodologies in land-use planning. The technological implementation of GIS is insufficient if it is decoupled from the socio-cultural context of the basin. Engaging local farmers in the data collection and interpretation phases ensures that the resulting digital models resonate with the community's specific needs and resource constraints. This collaborative process ensures that the strategies developed are culturally congruent and scientifically robust, leading to sustainable outcomes that are more likely to be adopted and maintained at the grassroots level. A participatory framework creates a feedback loop: researchers provide technological tools to visualize and analyze the landscape, while the community provides the experiential heuristics necessary to make sense of that data. Future research initiatives must prioritize the creation of institutionalized platforms for continuous, transdisciplinary dialogue, ensuring that local stakeholders, researchers and government agencies maintain a shared, evolving understanding of the changing landscape.

The implications of this research extend far beyond the geographical boundaries of the Brahmaputra Basin. As the global climate faces unprecedented shifts, the necessity for decentralized, resilient agricultural frameworks become universal. The model established by merging IK and GIS serves as a blueprint for other vulnerable riverine ecosystems globally, from the Mekong in Southeast Asia to the Amazon in South America. The methodologies pioneered here—characterized by the modularity of GIS and the adaptability of traditional knowledge—can be recalibrated to meet the specific environmental and cultural needs of diverse regions. By demonstrating that traditional knowledge is not a relic of the past but a dynamic, evolving data source, this research challenges the prevailing dichotomy between "modern" and "traditional" knowledge systems.

Ultimately, the goal of integrating GIS with Indigenous Knowledge is to establish a more equitable and effective approach to global food security. The resilience of communities inhabiting flood-prone regions is directly proportional to the degree to which their endogenous knowledge is valued and supported by technological advancement. Future climate adaptation strategies must move beyond superficial inclusion and commit to a deep, structural collaboration between all stakeholders. By fostering this synergy, we can develop agricultural landscapes that are not only robust against the physical threats of floods but are also grounded in a commitment to sustainable development, social justice and cultural heritage. The transition to a climate-resilient future depends on our ability to listen to the land through the ears of those who have sustained it for generations, while simultaneously using our most advanced navigational tools to see the future clearly. Such an approach does not merely prepare communities for the challenges of climate change; it reinforces the resilience of the agricultural systems upon which millions depend, marking a vital step toward a more sustainable global future.

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